

# Color

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Dr. Tushar Sandhan

# Introduction

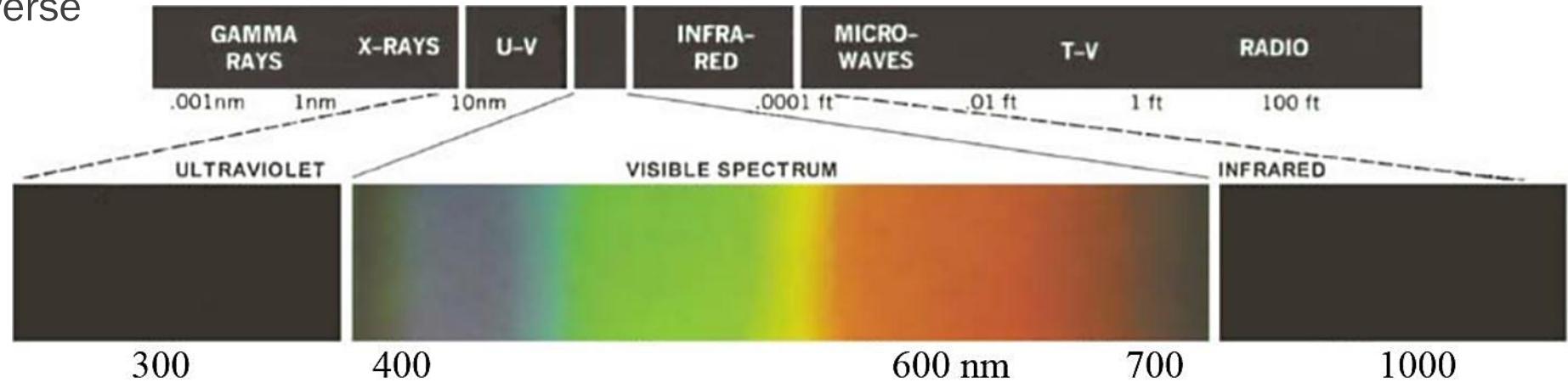
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- Color of the Universe

# Introduction

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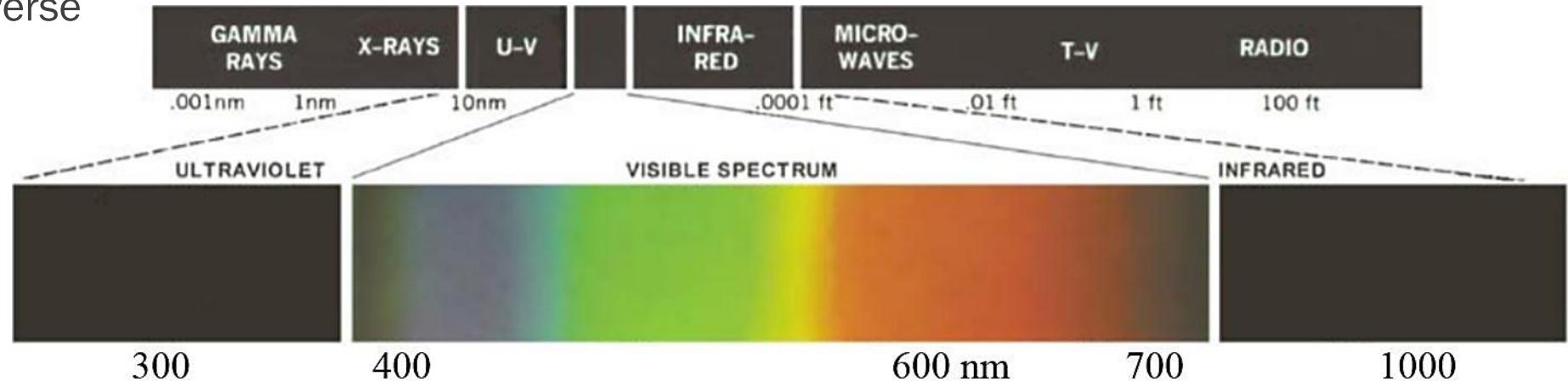
- Color of the Universe



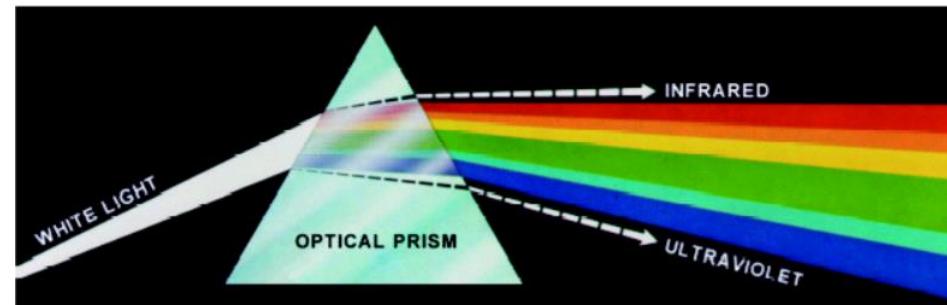
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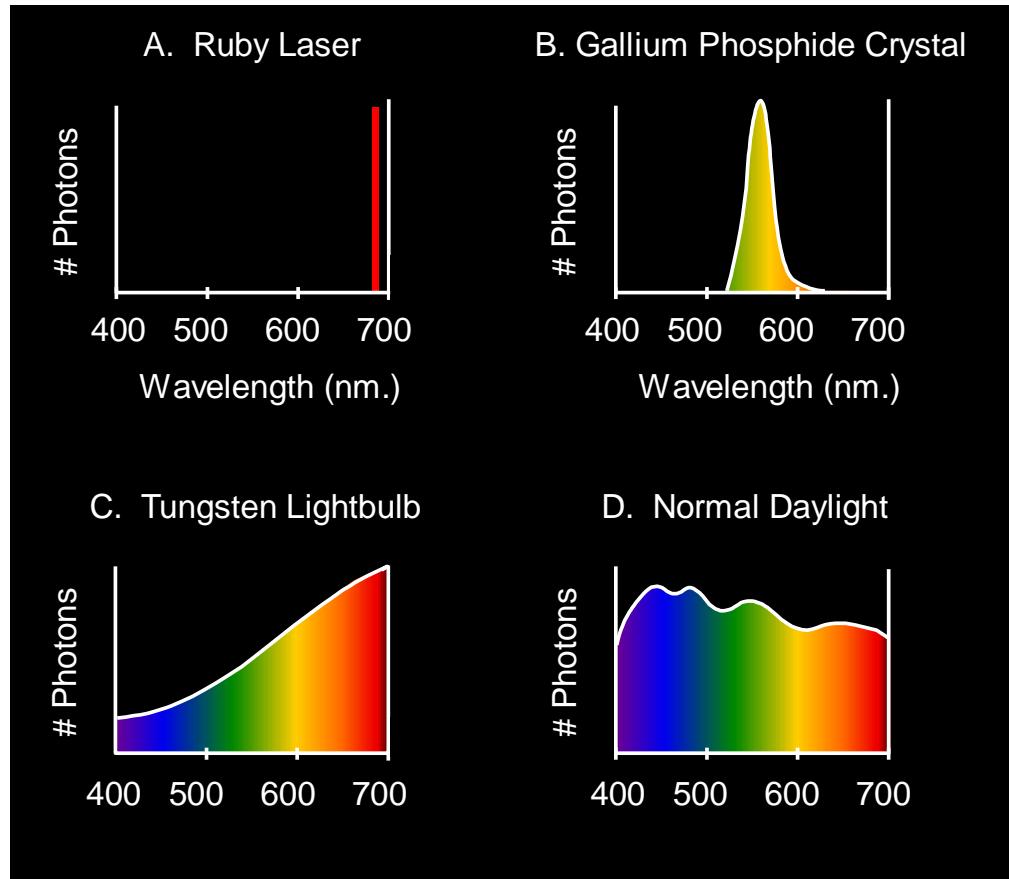


- Visible light (dispersion)



# Spectra of objects

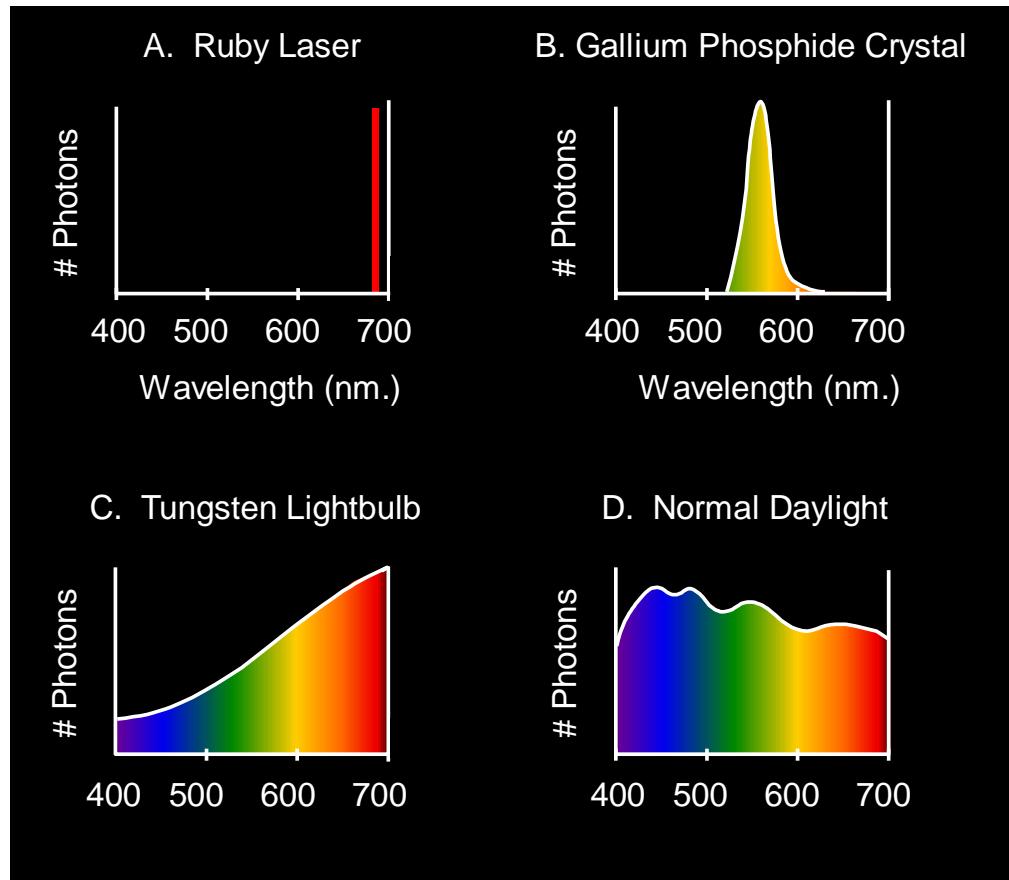
Light source spectra



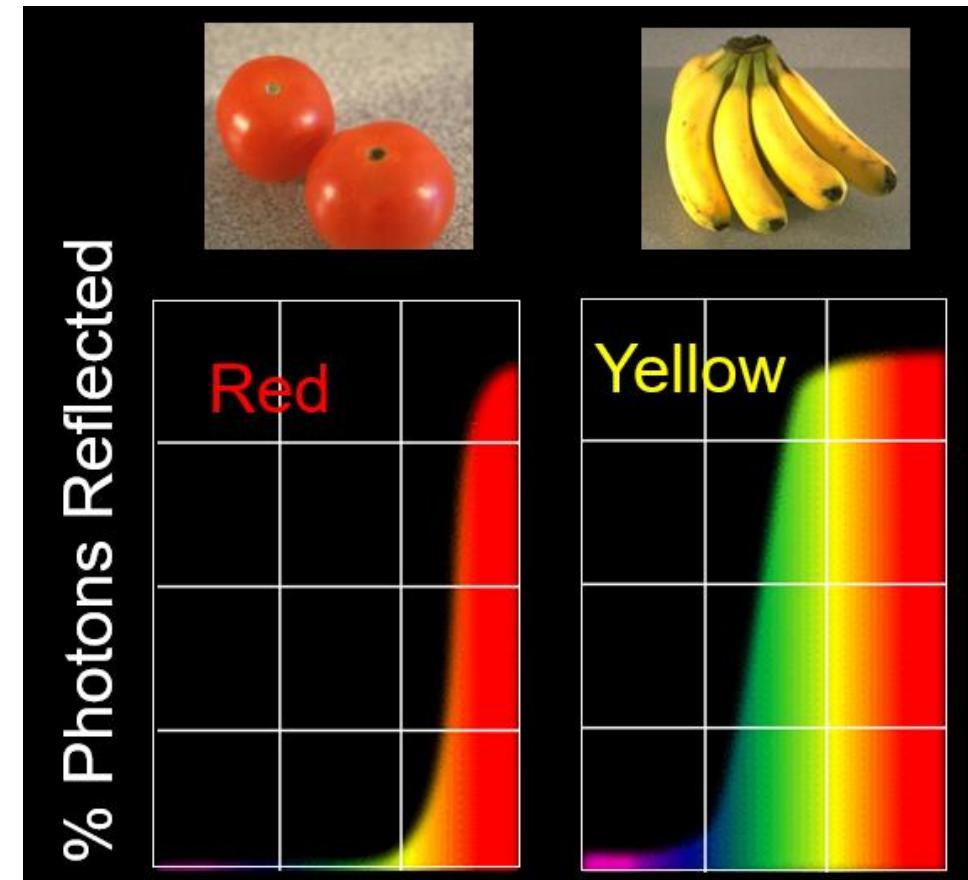
credit: E. Palmer

# Spectra of objects

Light source spectra



Reflectance spectra of surfaces

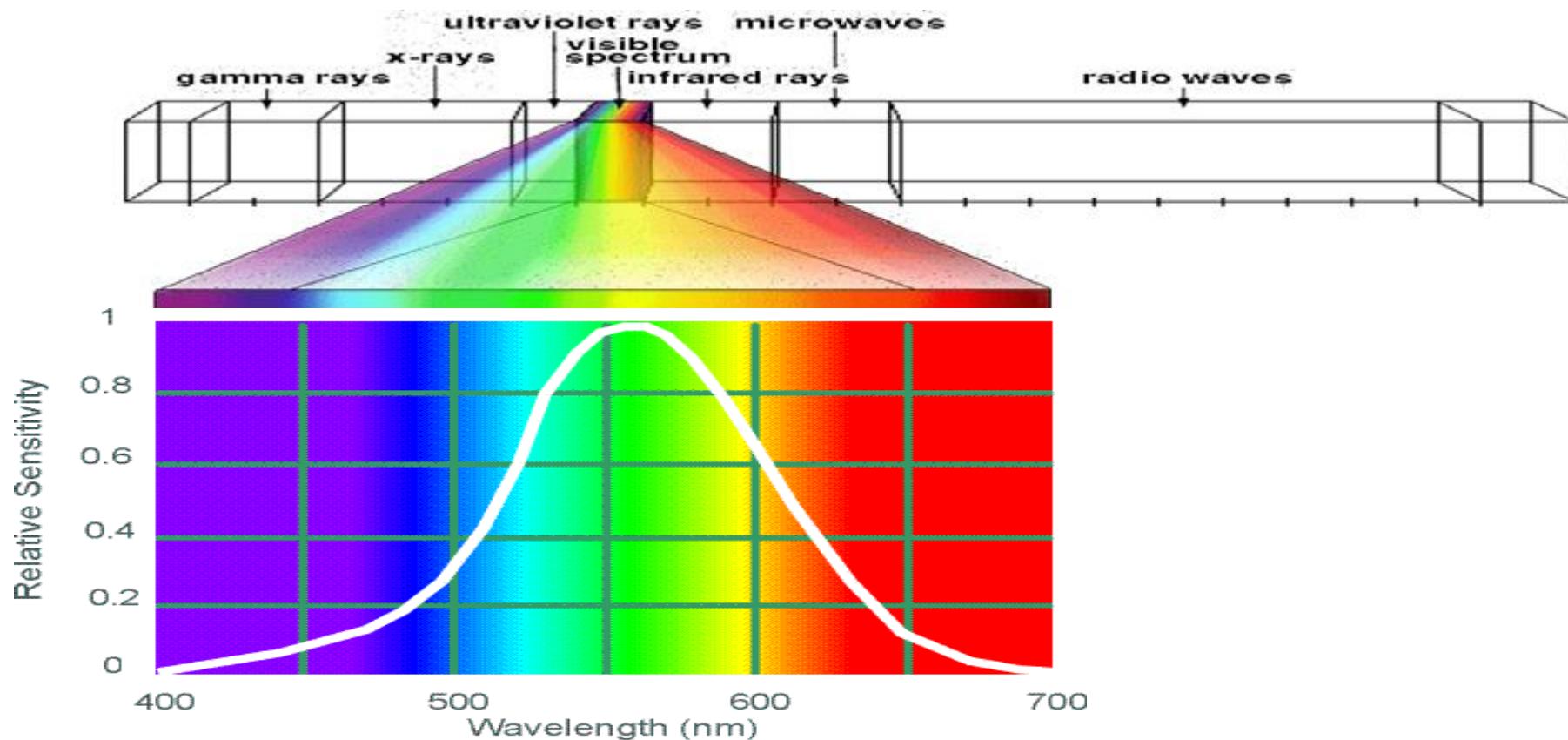


credit: E. Palmer

# Color

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- Human Luminance sensitivity



credit: Efros

# Color

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- Light spectrum is continuous,  
then why are images RGB?

# Color

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# Color

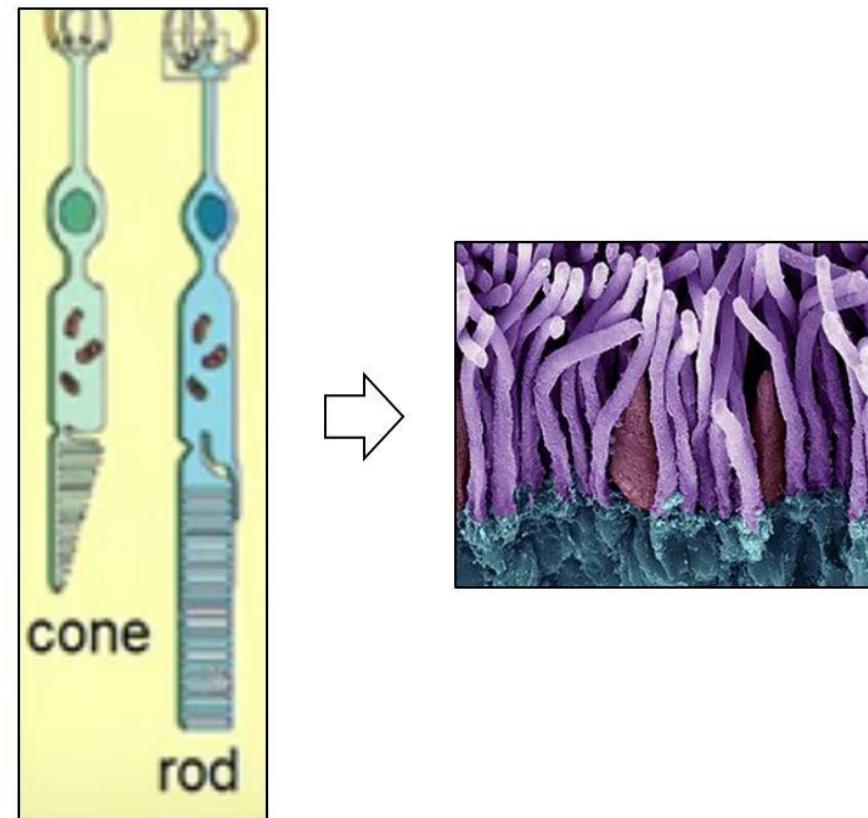
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- ▲ Evolutionary cones (6 million)

# Color

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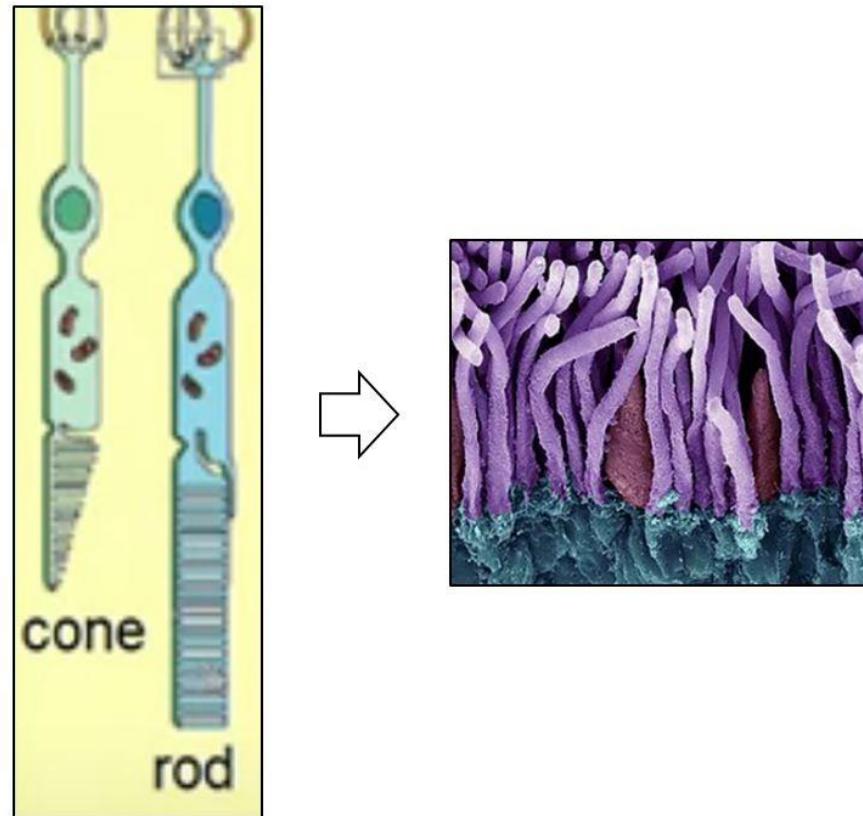
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then why are images RGB?

## ▲ Evolutionary cones (6 million)

- Characterization of cone cells & understanding visual process in the eye.

- Ragnar Granit, Haldan Keffer Hartline and George Wald
  - Nobel Prize 1967



# Color

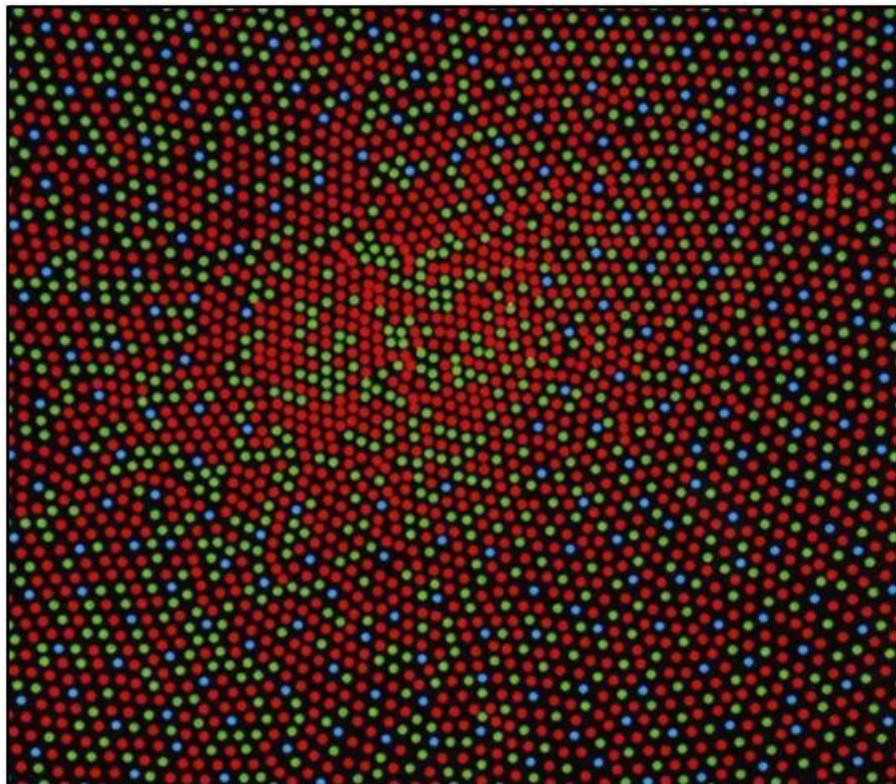
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- HVS retina display

# Color

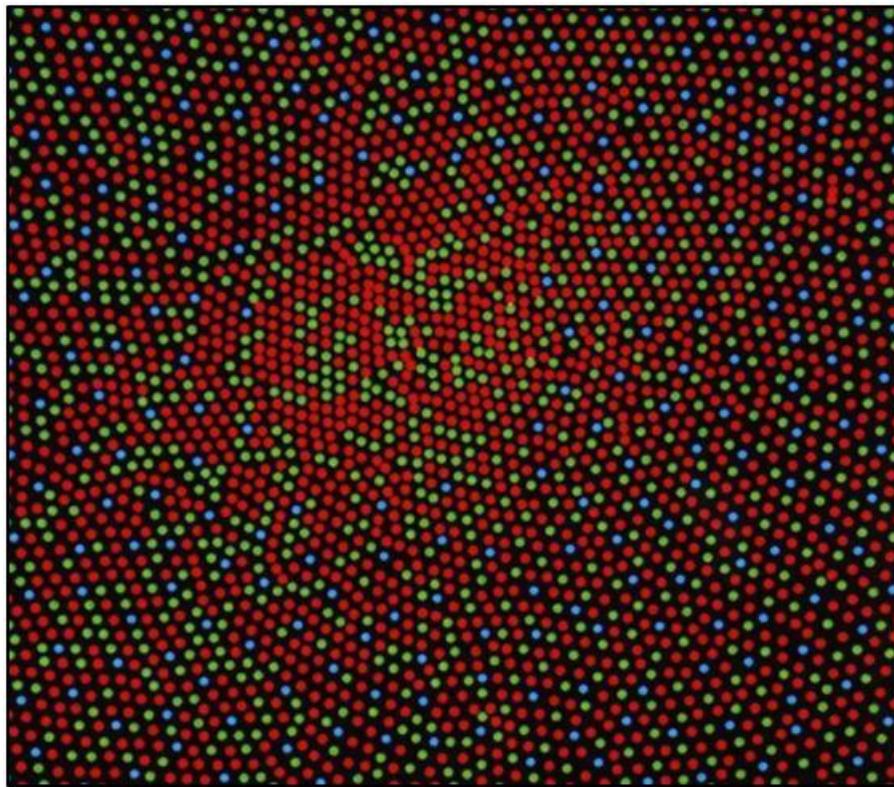
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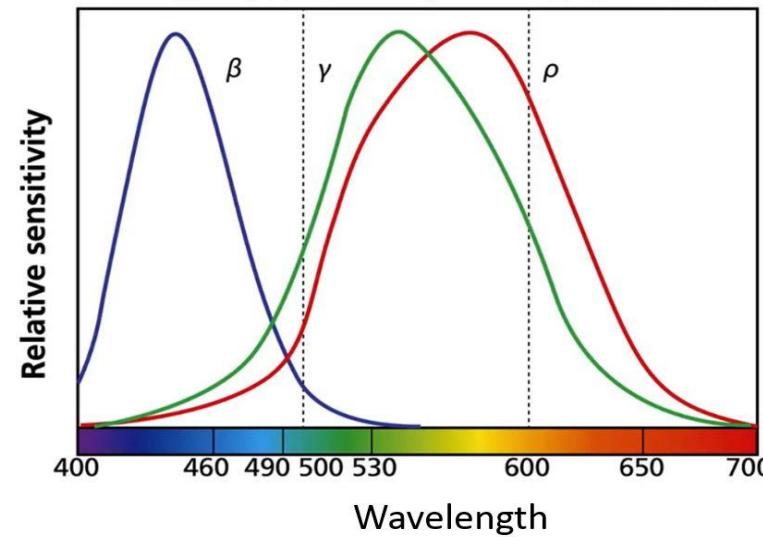


# Color

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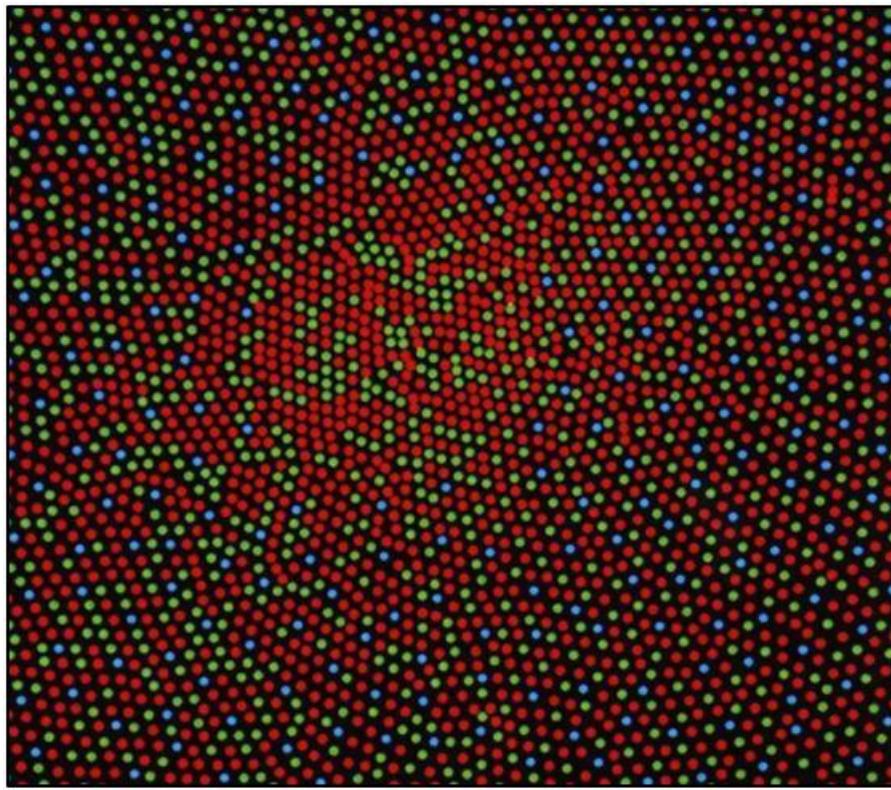


Three cone types ( $\rho$ ,  $\gamma$ ,  $\beta$ ) correspond roughly to R, G, B.

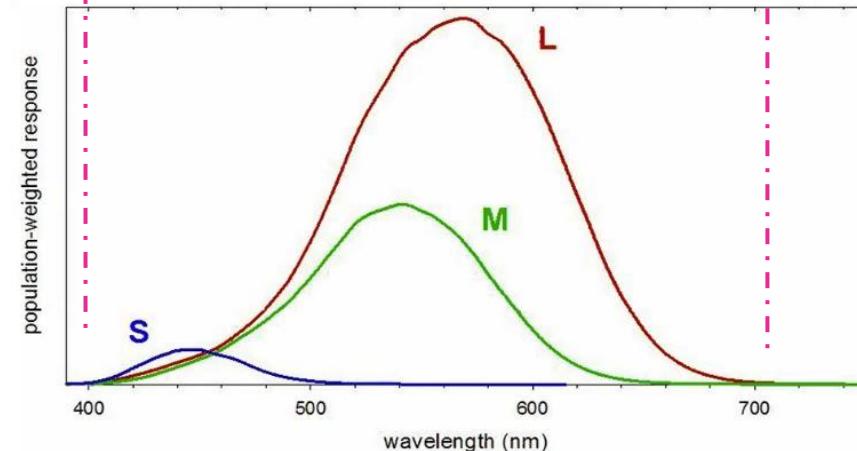
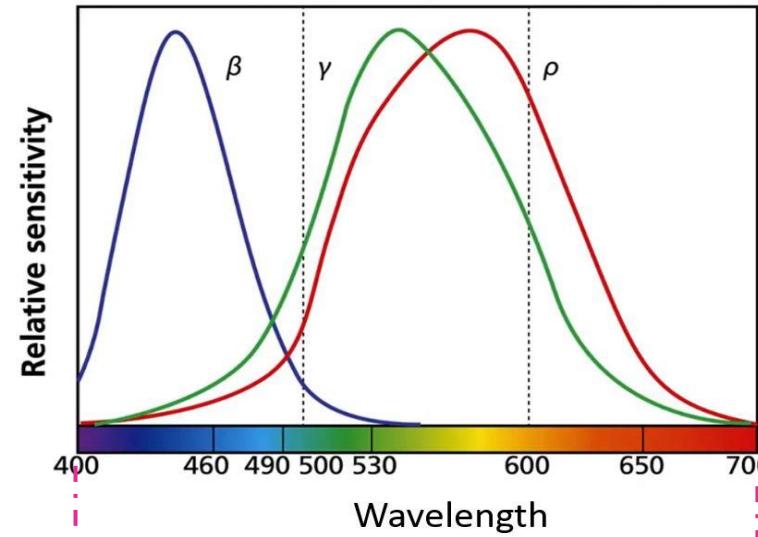


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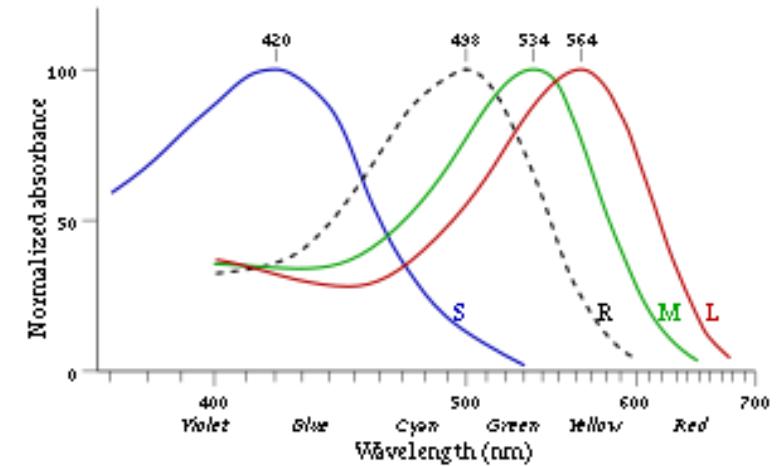
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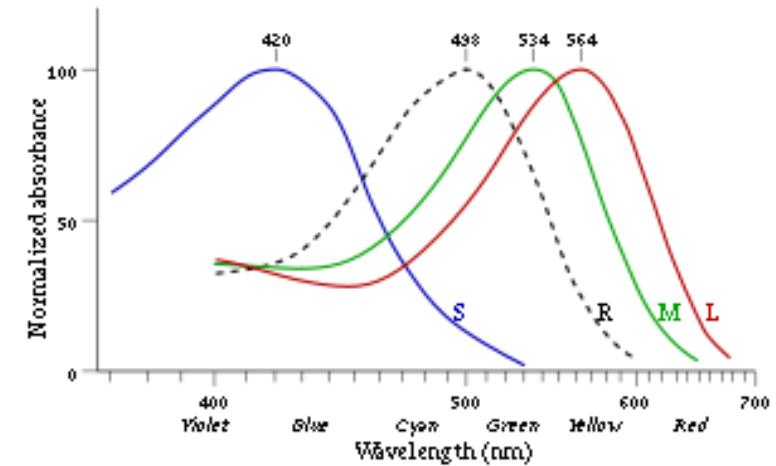
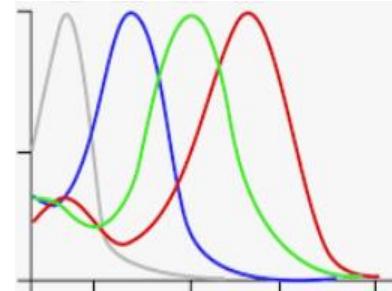
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- Cones (Long:L, Medium:M, Short:S) & Rods:R
- S: blue (most sensitive)
- M, L on chromosome X (some women are tetrachromatic)



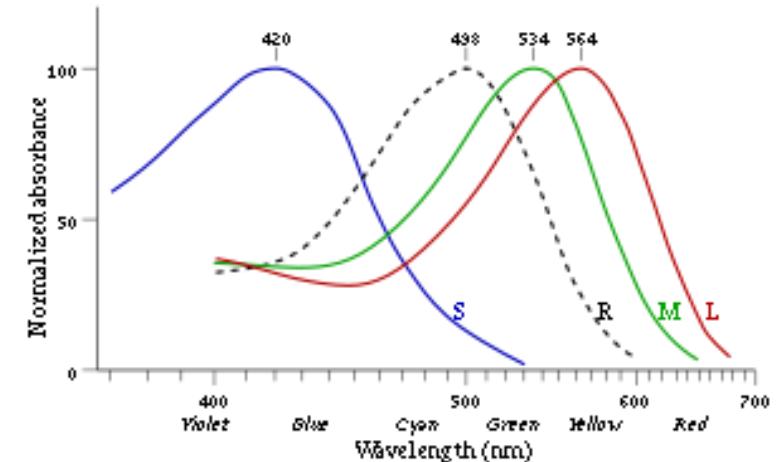
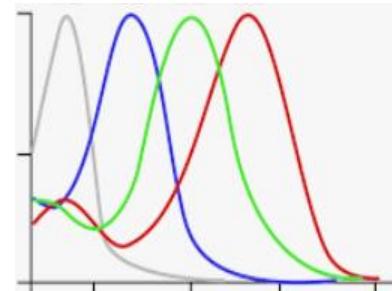
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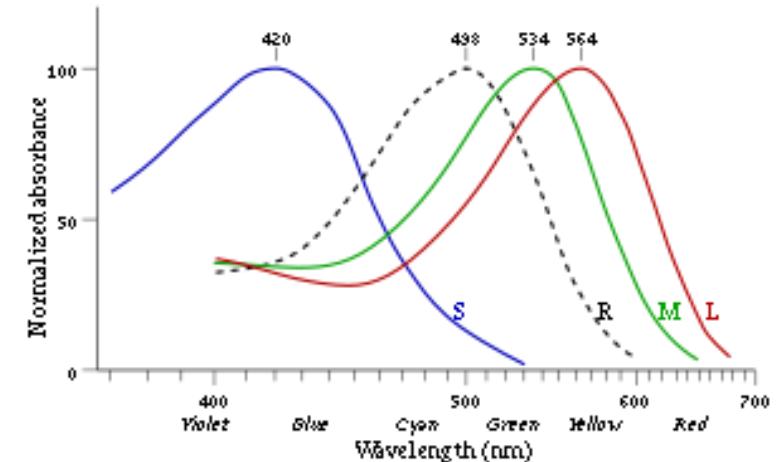
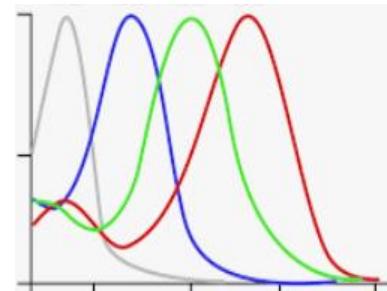
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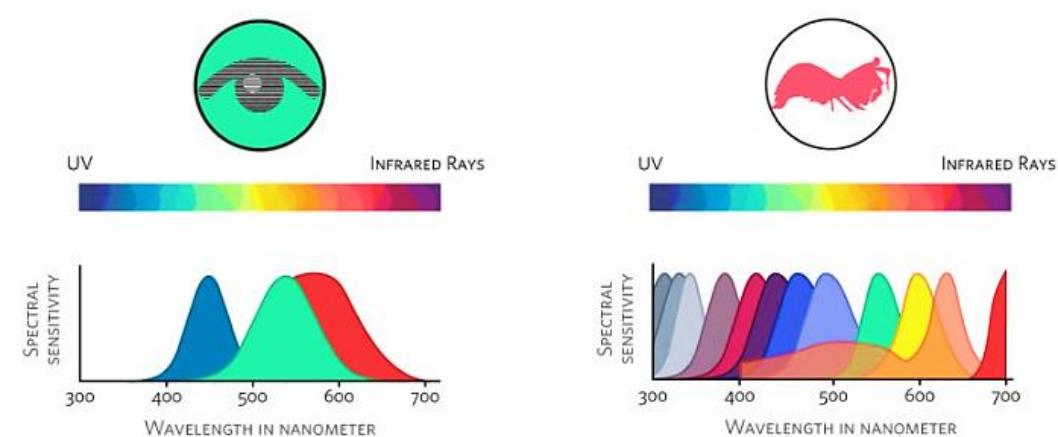
- Reptiles : 5 types of cones
- Mantis shrimp: 12 types of cones

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- What is it?

# Color

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  - ▶ psychophysical: physiological sequence of sensory processing
  - ▶ perceptual: cognitive representation of a physical reality

# Color

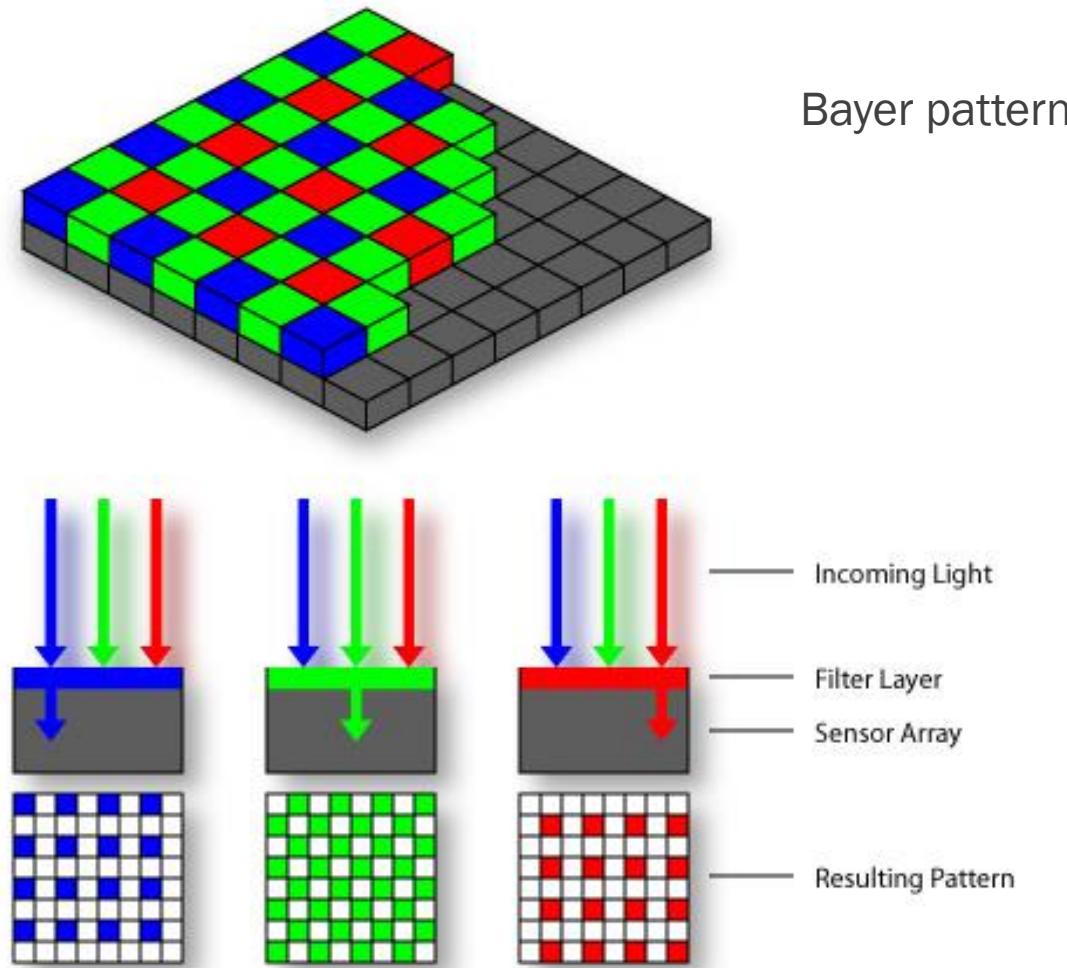
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- What is it?
  - ▶ psychophysical: physiological sequence of sensory processing
  - ▶ perceptual: cognitive representation of a physical reality
- Imagination of the illuminated retina!

# Color

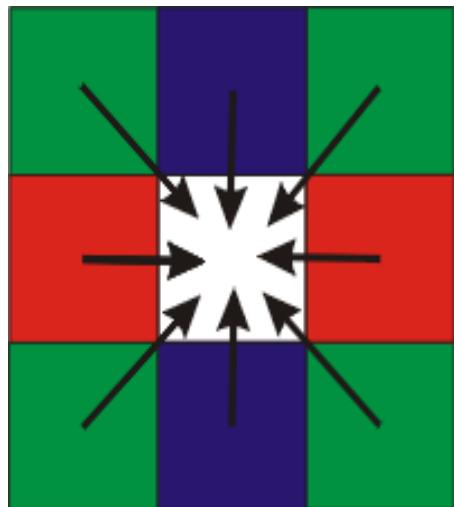
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- Sensing

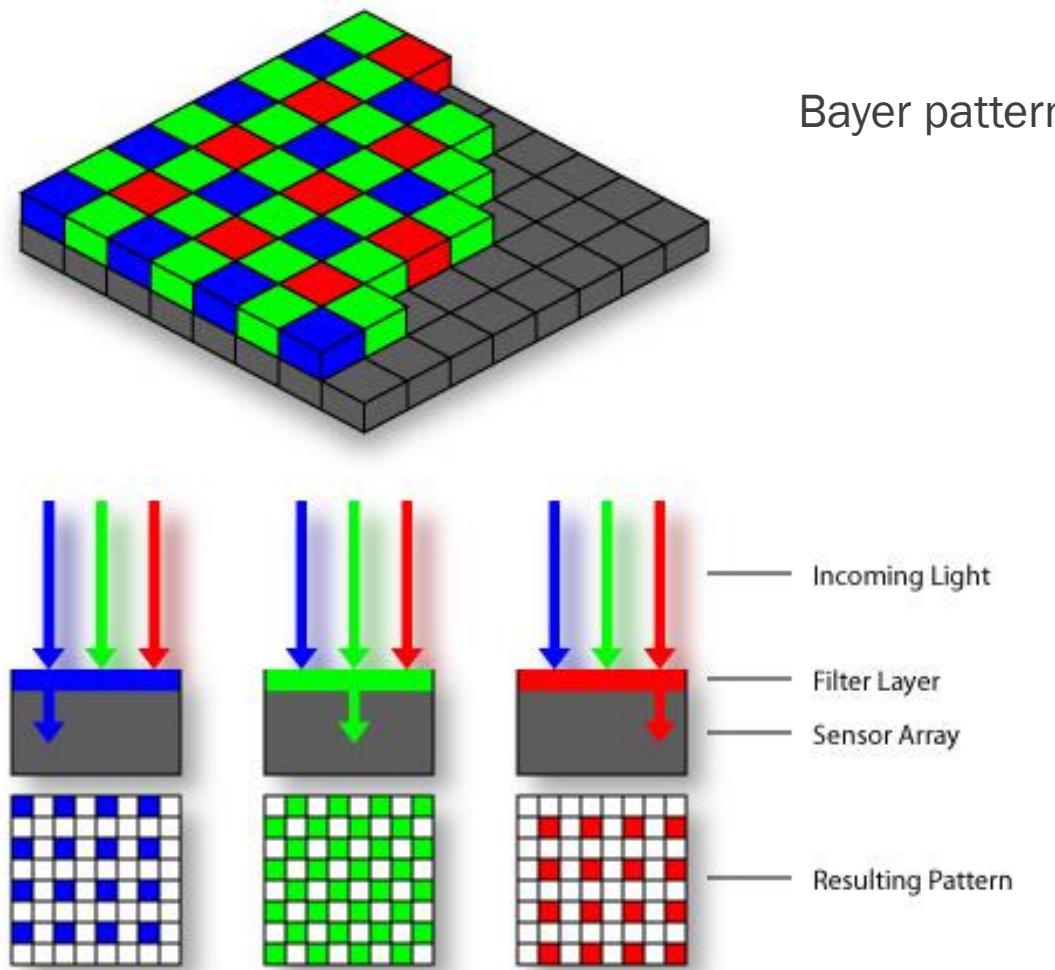


# Color

- Sensing



Estimate the color



# Color

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- Representation

- for graphics & displays

- CIE chromaticity diagram
    - Commission Internationale de l'éclairage-1931
    - inks, displays, cameras
    - X – mix of RGB
    - Y – illuminance
    - Z – close to blue

- for computational analysis

- color spaces
    - processing the color images

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- Hunt-Pointer-Estevez matrix

- cone responses to XYZ mapping
    - LMS: cone responses of human eye
    - $Z \leftrightarrow S$
    - Y – brightness
    - X, Z - chromaticity

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$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1.910\ 20 & -1.112\ 12 & 0.201\ 91 \\ 0.370\ 95 & 0.629\ 05 & 0 \\ 0 & 0 & 1.000\ 00 \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}_{\text{HPE}}$$

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- CIE Chromaticity diagram
  - concept of color for computations
    - brightness (white > grey)
    - chromaticity (white = grey)

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  - derived parameters for chromaticity
    - x, y
    - normalized function of all tristimulus values
    - Tristimulus: a color is represented by its trichromatic coefficients X, Y, Z

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$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z} = 1 - x - y$$

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$$X = \frac{Y}{y}x,$$
$$Z = \frac{Y}{y}(1 - x - y).$$

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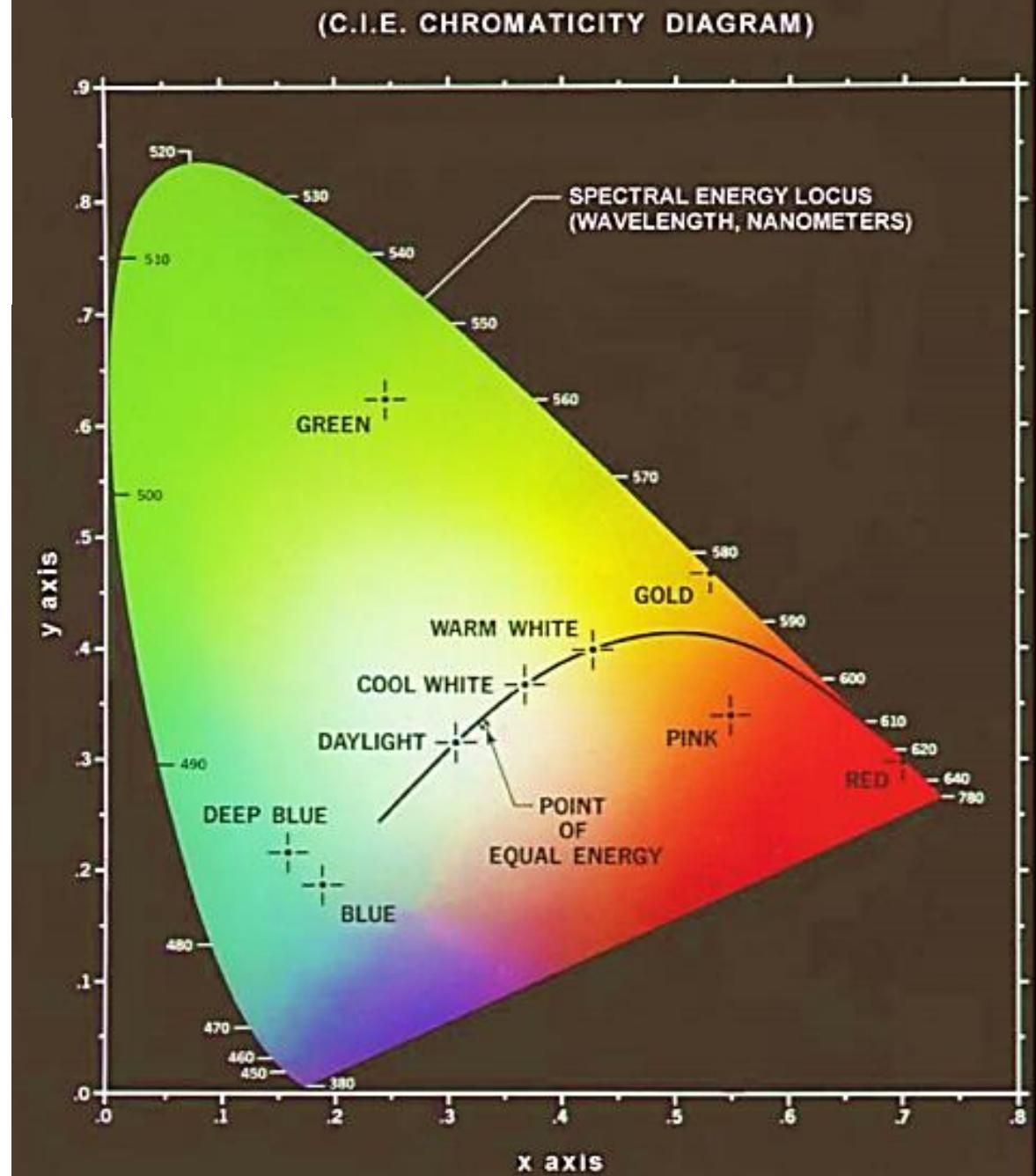
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  - specifies how human eye will experience light with a given spectrum

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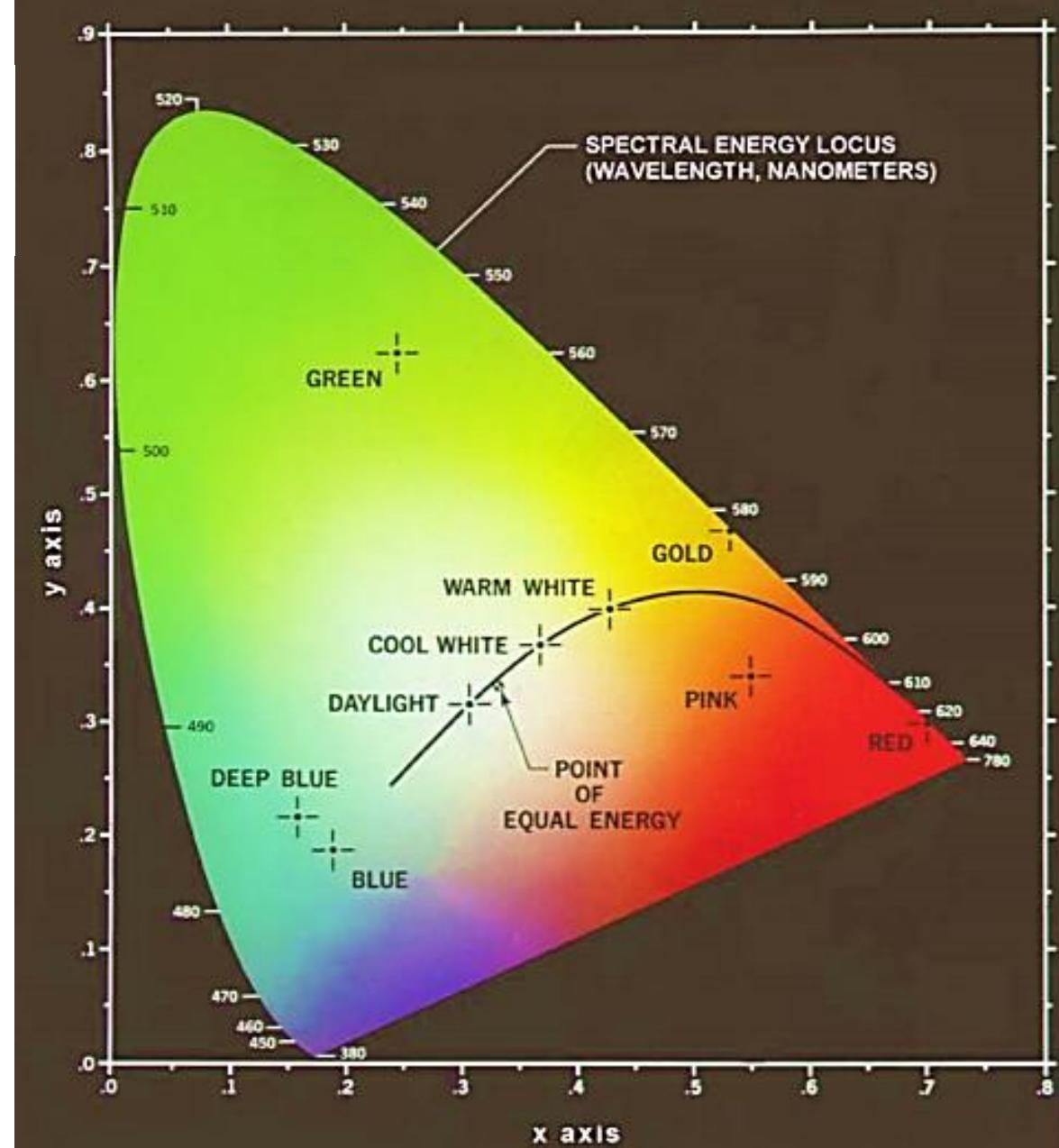
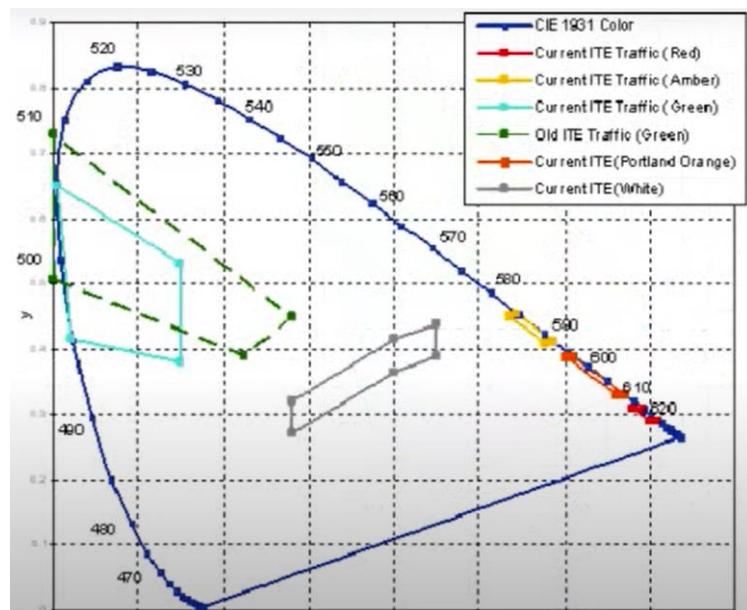
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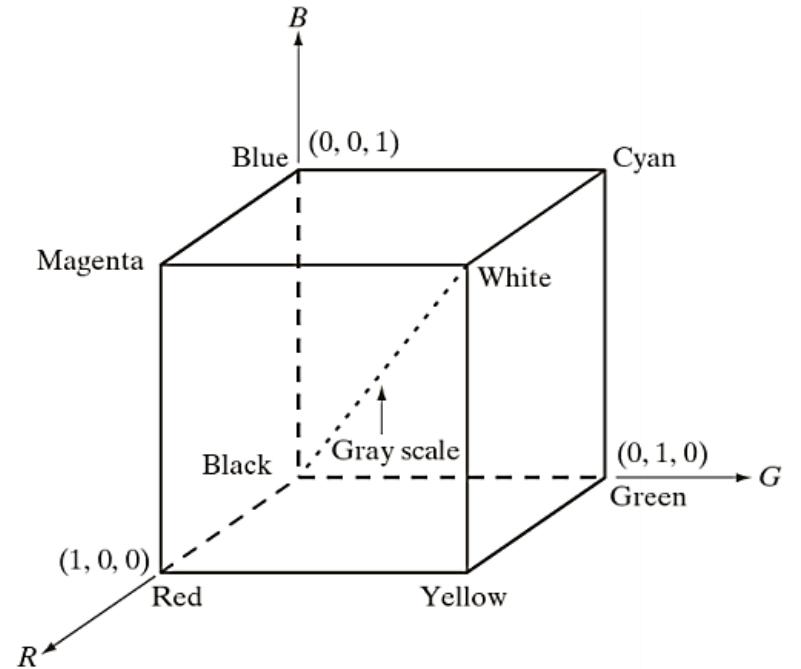
Traffic light specifications



# Color spaces: RGB cube

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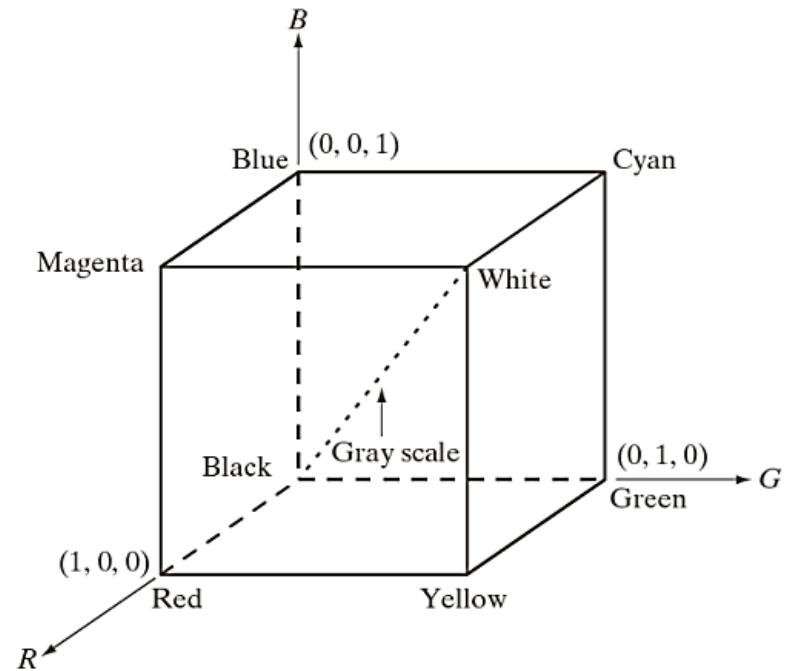
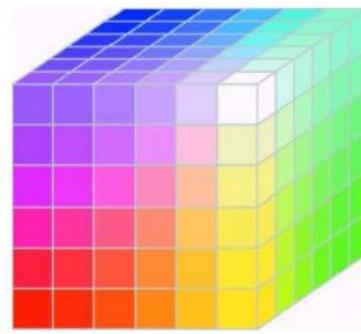
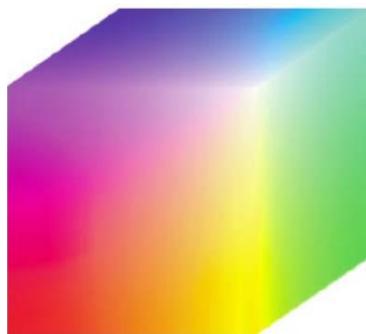
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- How many possible colors in computer with 3 bytes?
- You can manipulate image inside this cube



# Color spaces: RGB cube

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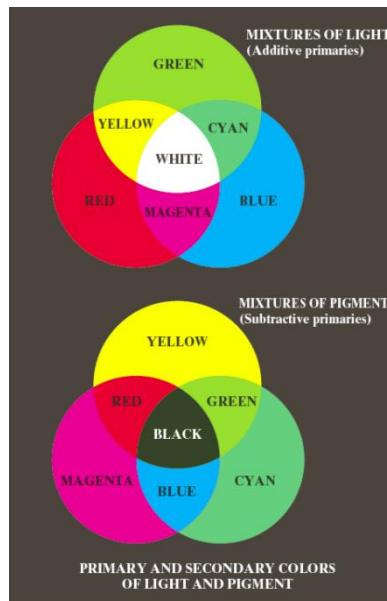
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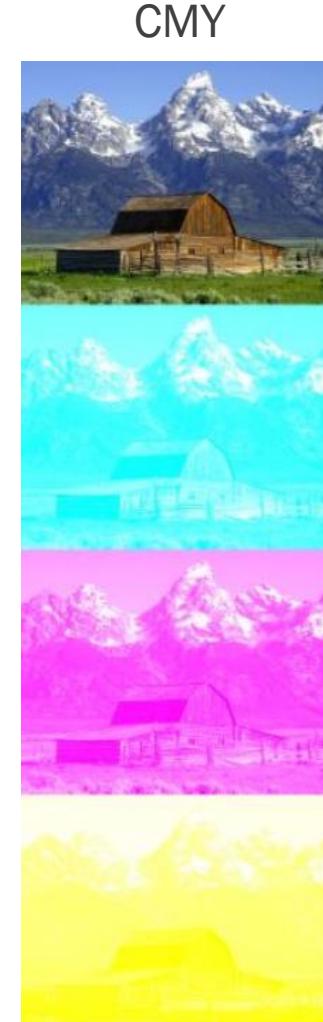
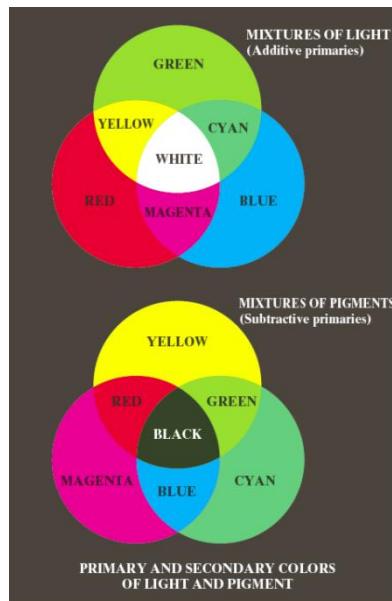
---

- Printer vs display
- $CMY = 1 - RGB$  (vector notation)
- what is  $C + M + Y = ?$
- to compensate muddy black, 'K' is added : CMYK  
 $K = 1 - \max(r, g, b)$   
find out other components?
- hint:  $C = (1-r-K)/(1-K)$



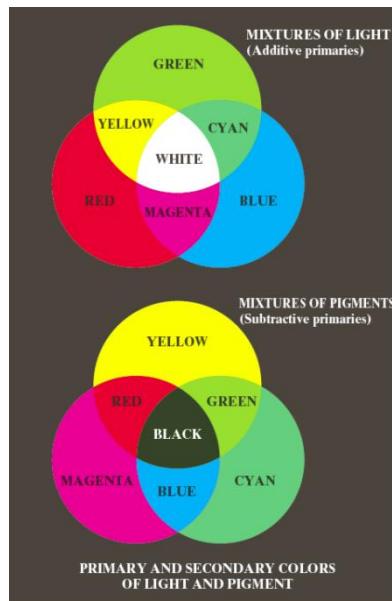
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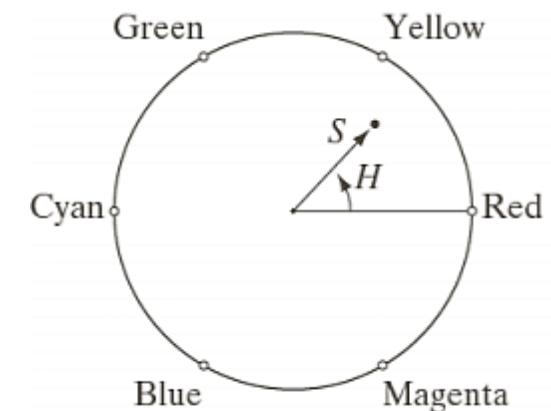
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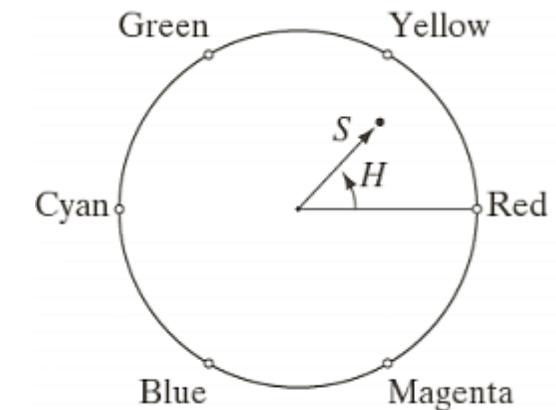
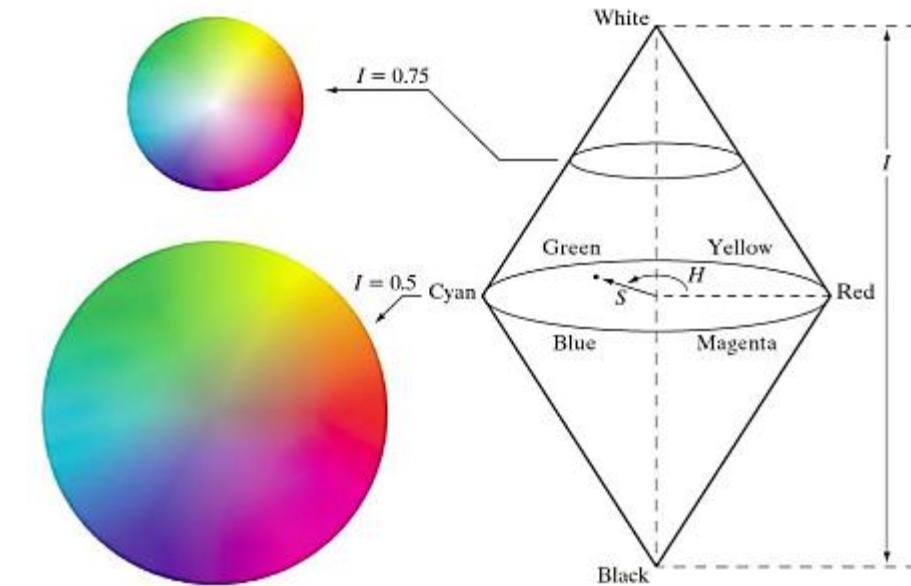
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- Hue:
  - dominant wavelength in the mixture of light waves
  - dominant color as perceived by us
- Saturation:
  - relative purity
  - amount of white light mixed in hue to get a color
- Value:
  - also called brightness
  - achromatic notion of intensity



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# Travelling inter-spaces

---

- It's nothing but converting image from one space to another

$$I = \frac{1}{3}(R + G + B)$$

$$S = 1 - \frac{3}{R+G+B} \min(R, G, B)$$

$$H = \begin{cases} \theta & B \leq G \\ 360 - \theta & B > G \end{cases}$$

where

$$\cos \theta = \frac{\frac{1}{2}[(R - G) + (R - B)]}{[(R - G)^2 + (R - B)(G - B)]^{1/2}}$$

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## RGB to HSV color conversion

Enter 6 digits hex code or enter red, green and blue color levels (0..255) and press the *Convert* button:

Enter RGB hex code (#):

or

Enter red color (R):

Enter green color (G):

Enter blue color (B):

Hue (H):  °

Saturation (S):  %

Value (V):  %

Color preview: 

# Color correction

---

- Acquired image might be in different illumination or in shadow

$$\begin{bmatrix} \tilde{r} \\ \tilde{g} \\ \tilde{b} \end{bmatrix} = \begin{bmatrix} \alpha_r & 0 & 0 \\ 0 & \alpha_g & 0 \\ 0 & 0 & \alpha_b \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

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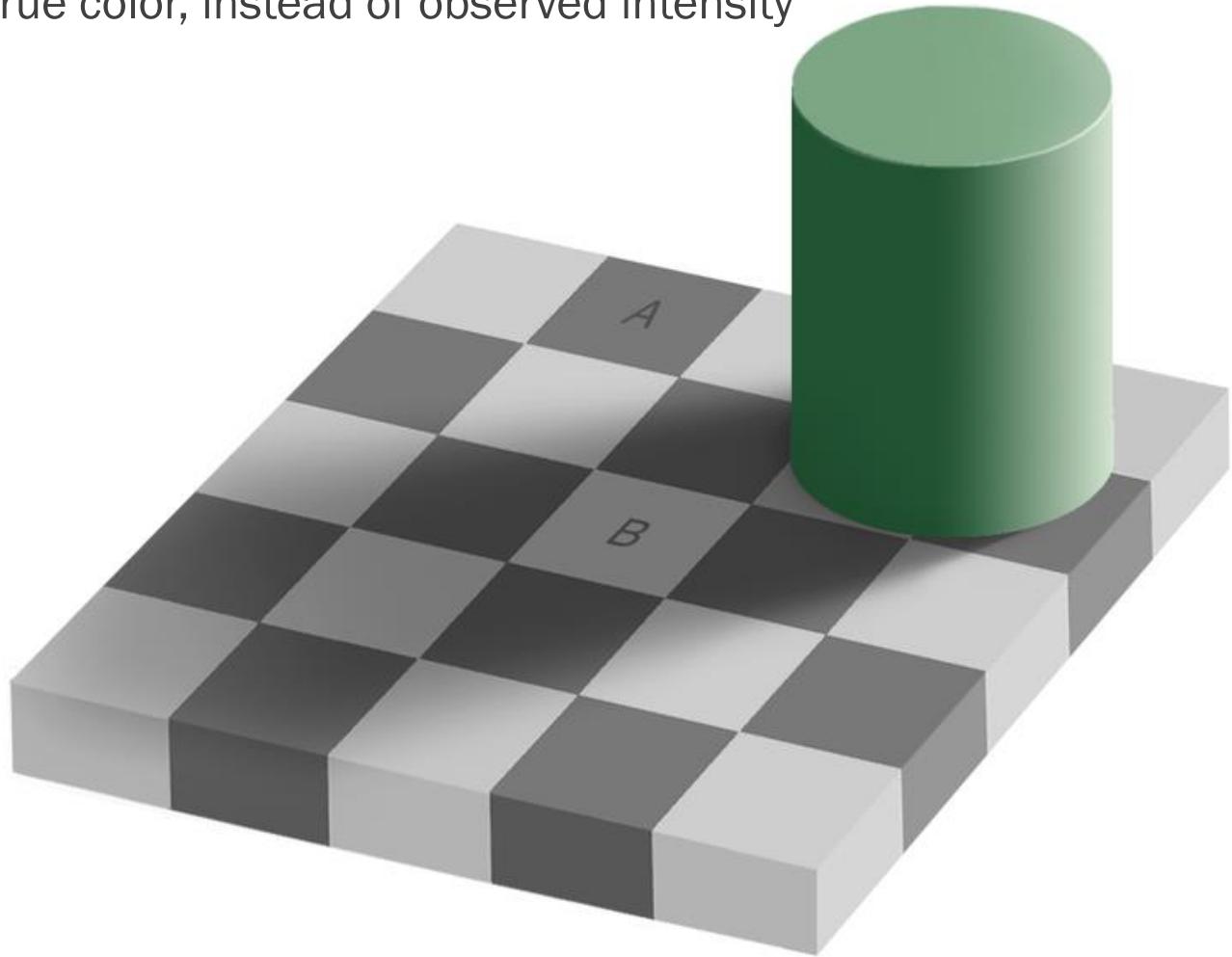
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- White world assumption: brightest pixel should be white
  - divide by max value
- Gray world assumption: average value should look like grey
  - $m = \text{avg over image} [ (r+g+b)/3 ]$
  - $\tilde{r} = r * \text{avg}(r)/m$
- Histogram equalization on color channels

# Color constancy

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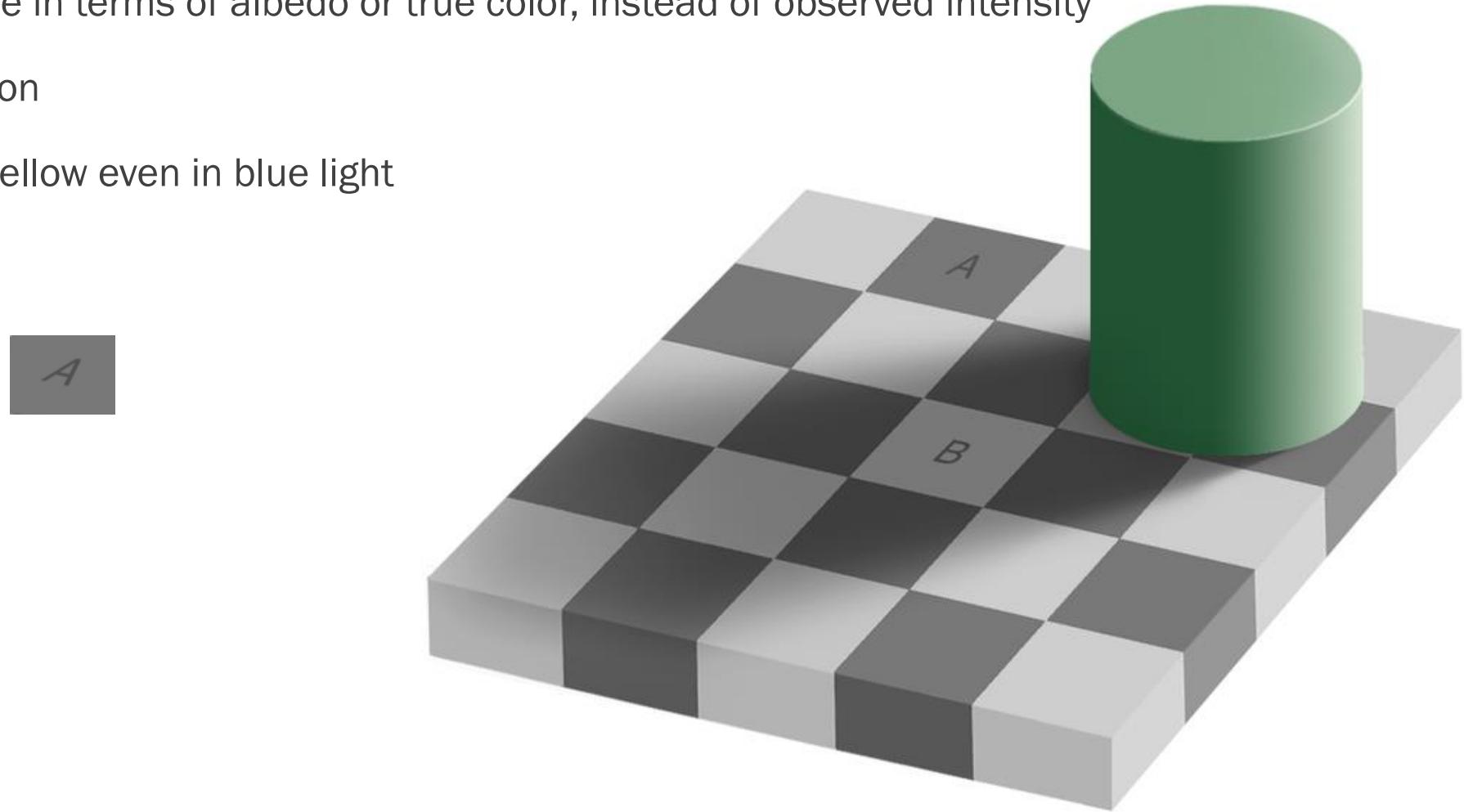
- Interpret object surface in terms of albedo or true color, instead of observed intensity
- Contextual phenomenon
- e.g. banana appears yellow even in blue light



# Color constancy

---

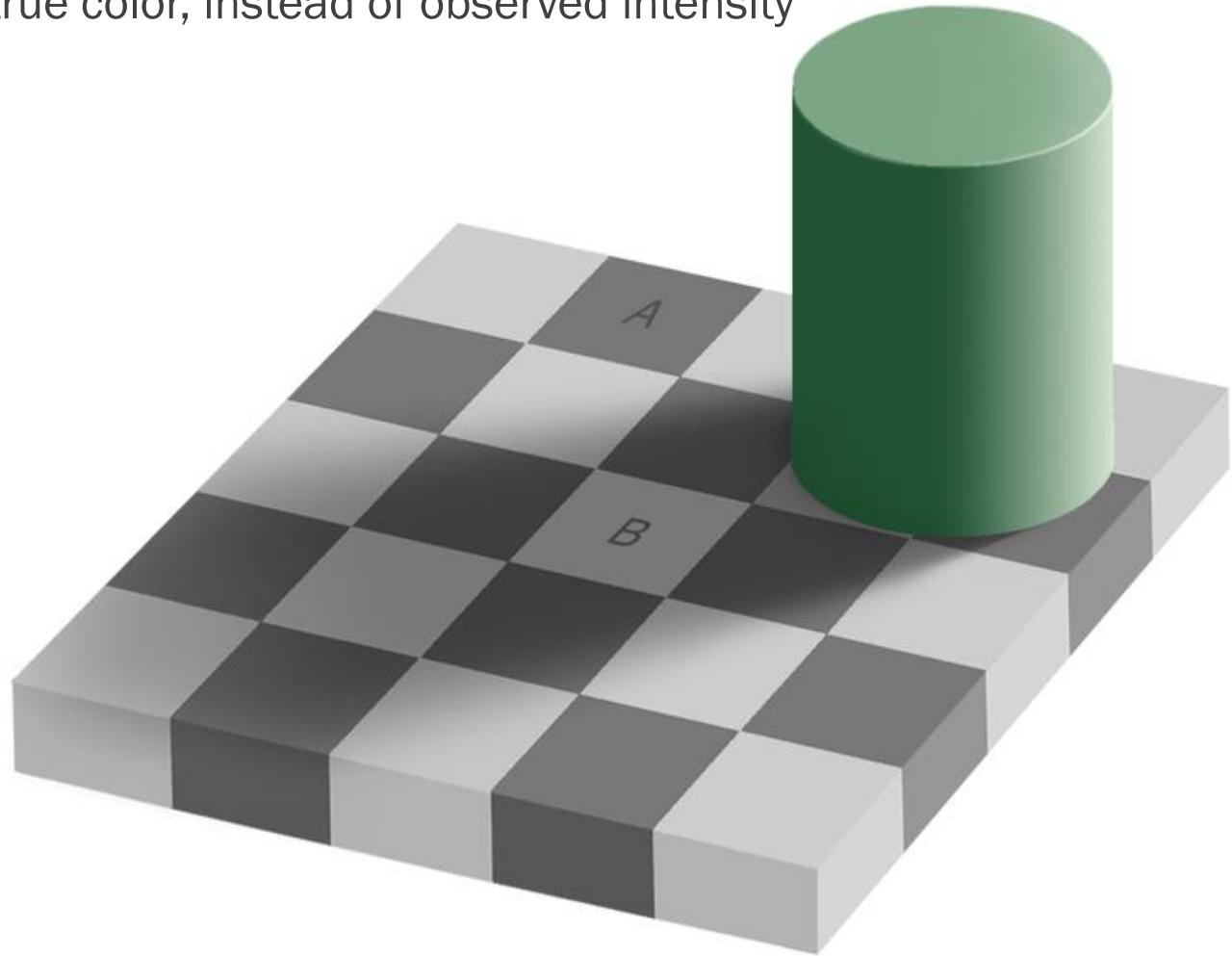
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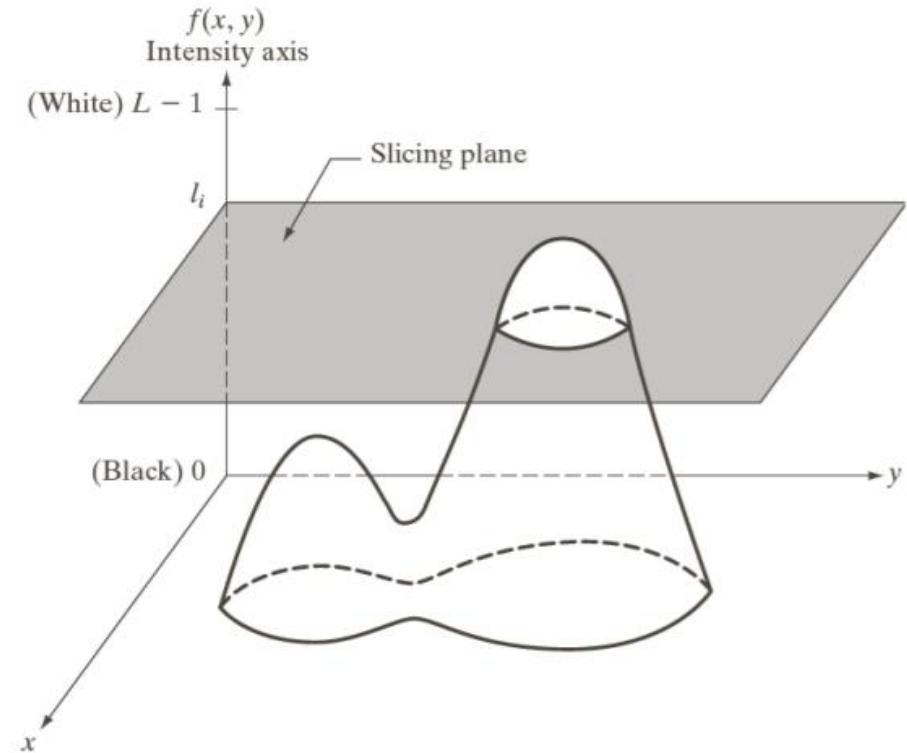
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# Pseudocolor image processing

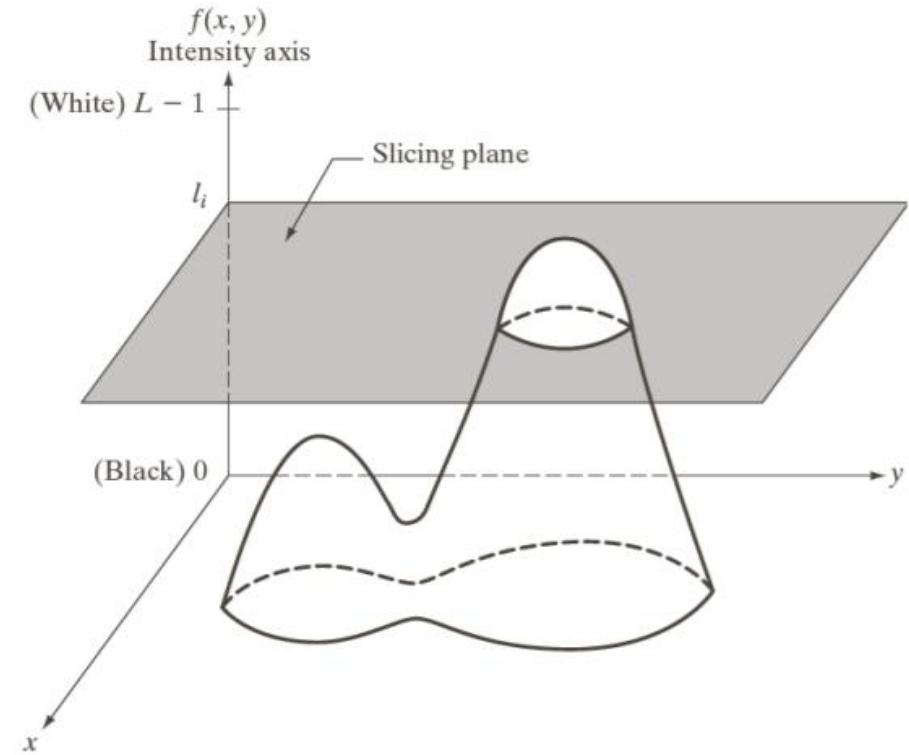
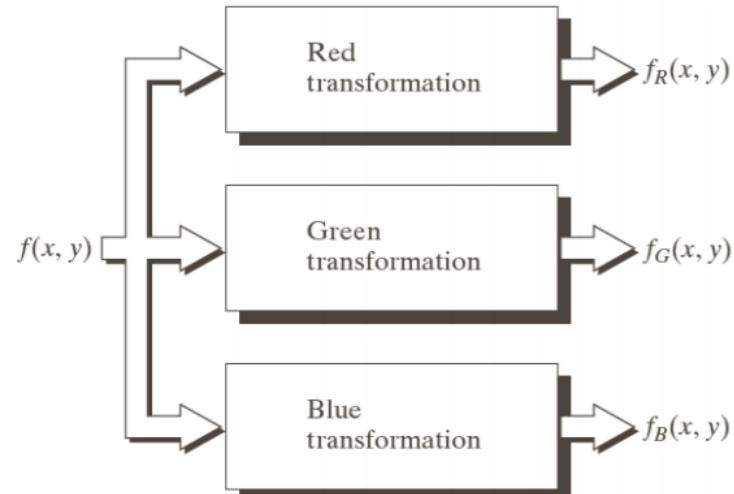
---

- assign colors to grey values (e.g. via intensity slicing)
- Note: different from image colorization  
(estimate underlying true color for a given grey image)



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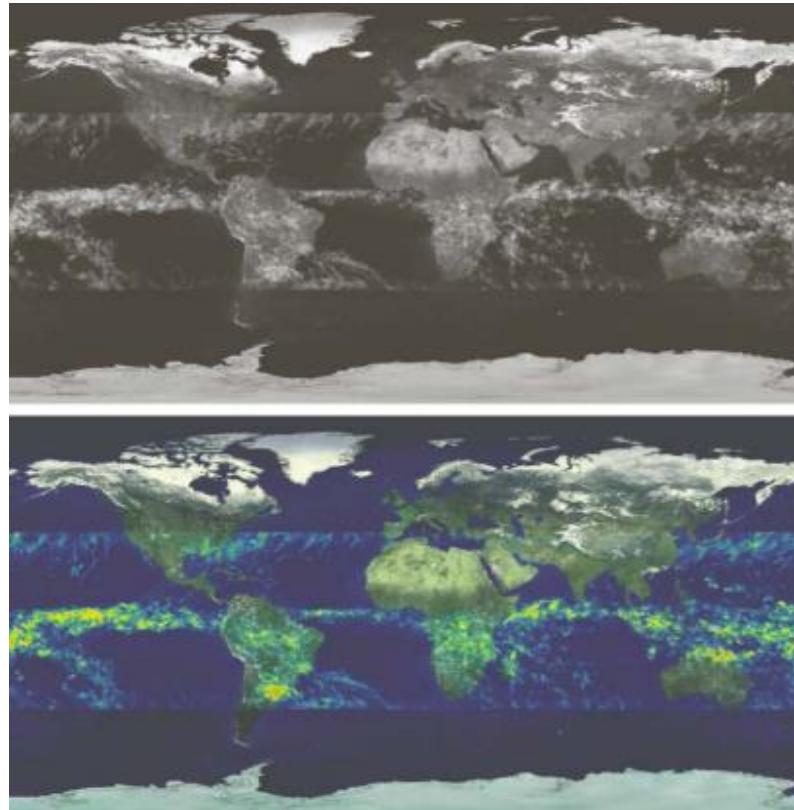
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satellite

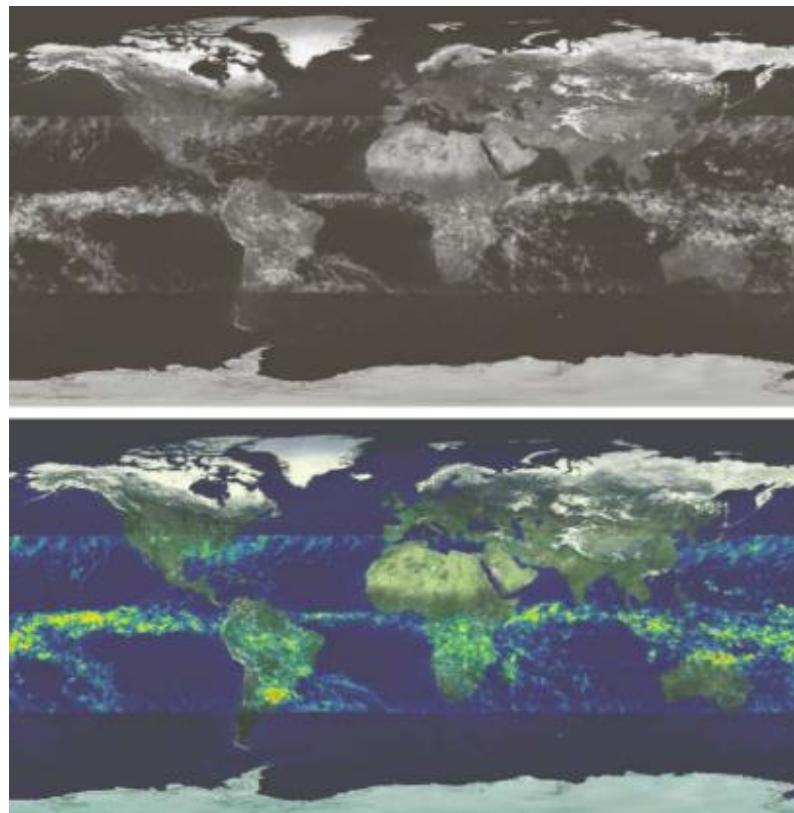


Credit: U. Berkeley & NASA

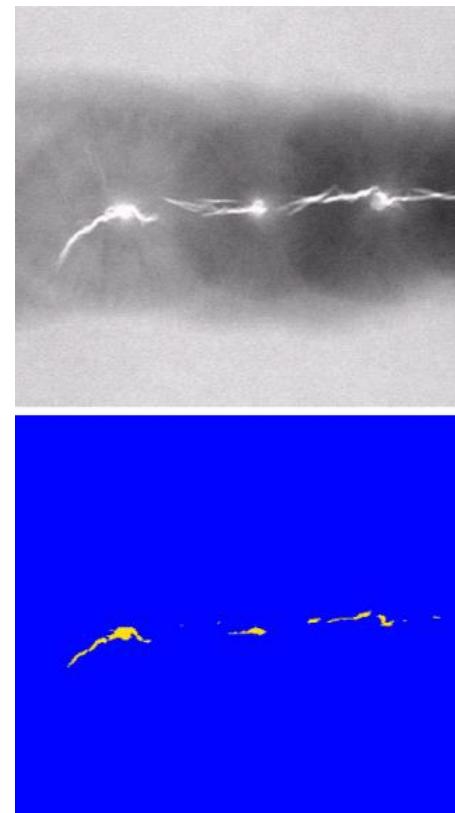
# Pseudocolor image processing

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satellite



X-ray

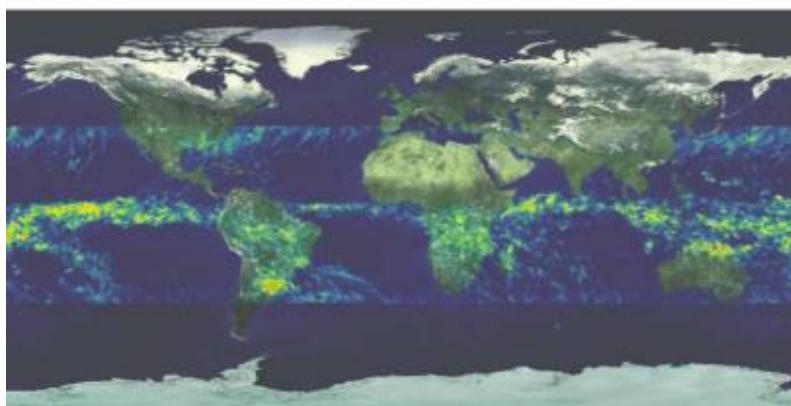
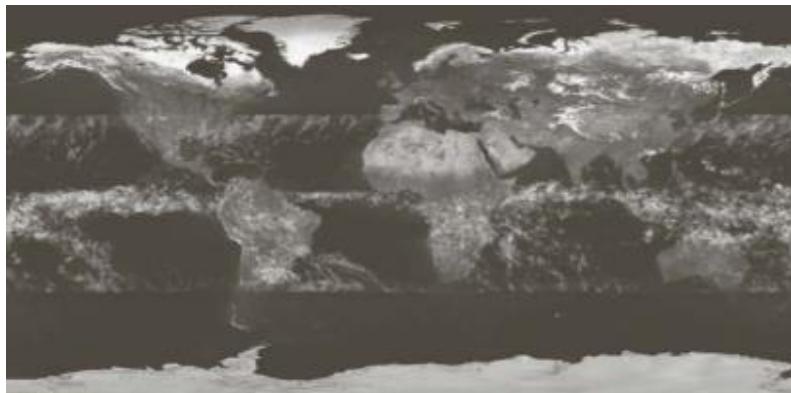


Credit: U. Berkeley & NASA

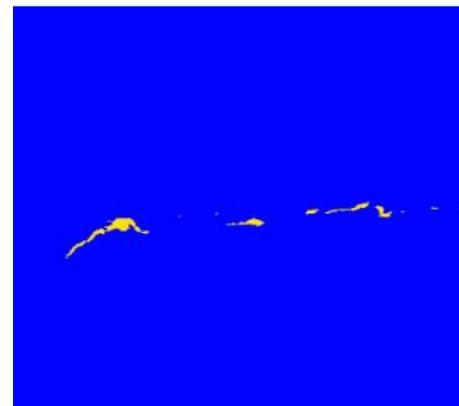
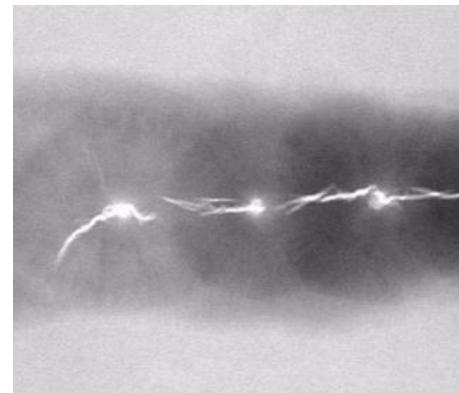
# Pseudocolor image processing

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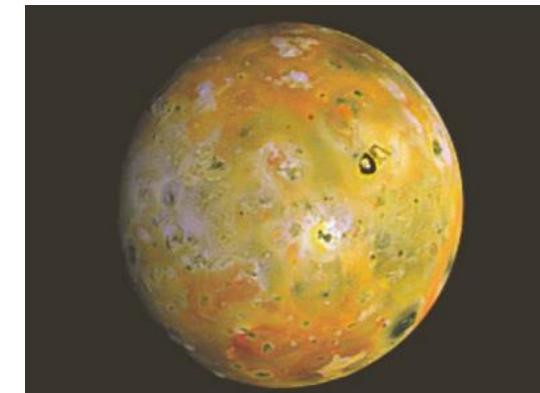
satellite



X-ray



Multi-sensors



Credit: U. Berkeley & NASA

# Pseudocolor image processing

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- Transformation functions

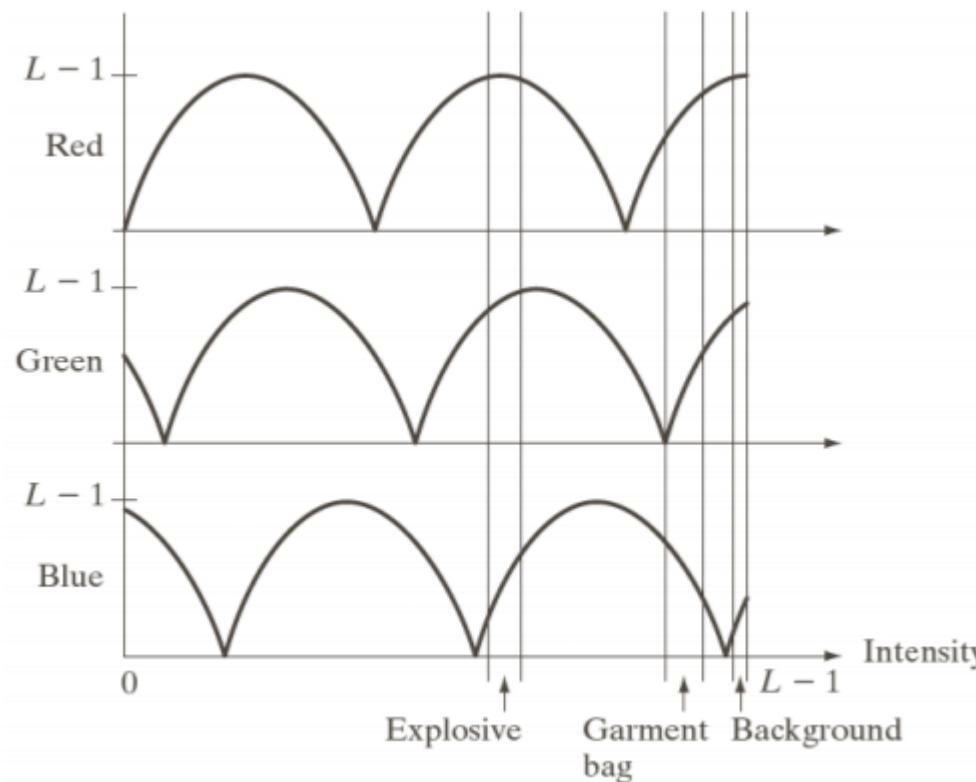
Input X-ray image



# Pseudocolor image processing

- Transformation functions

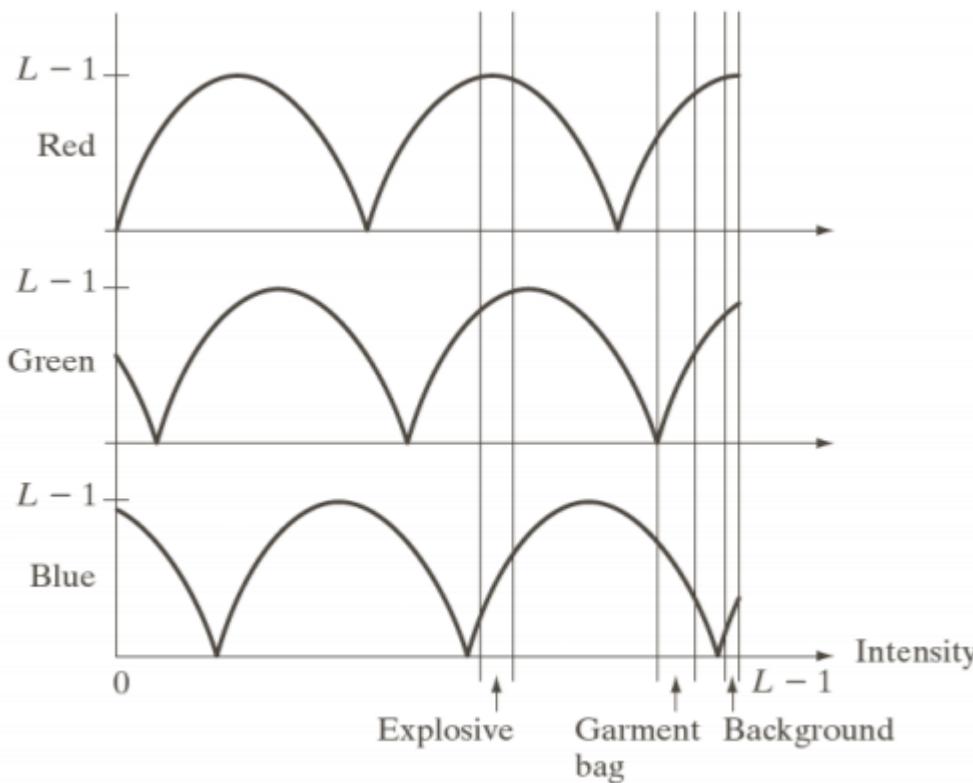
Input X-ray image



# Pseudocolor image processing

- Transformation functions

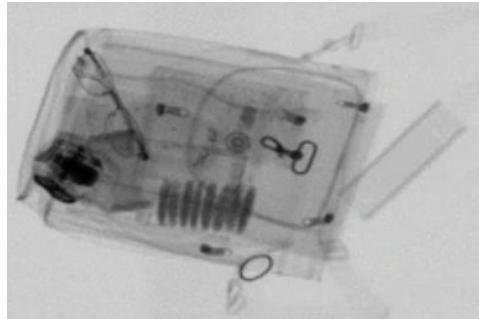
Input X-ray image



# Pseudocolor image processing

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- Transformation functions
  - with different transformation functions

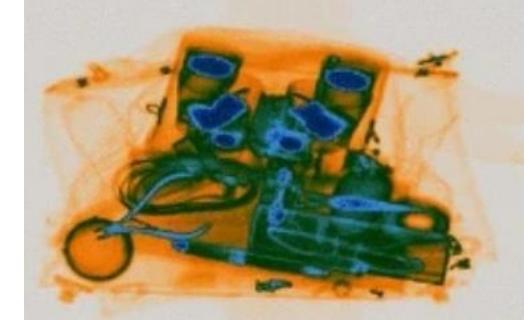
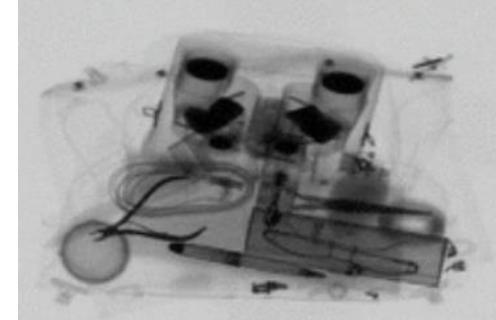
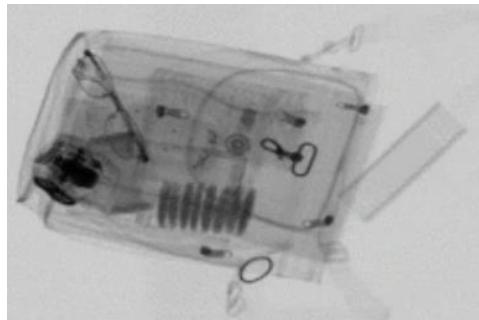


Credit: K. Dmitruk et al.

# Pseudocolor image processing

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- Transformation functions
  - with different transformation functions

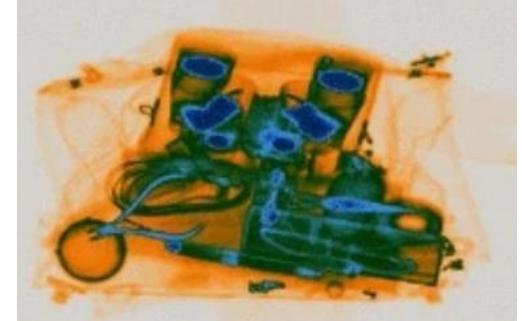
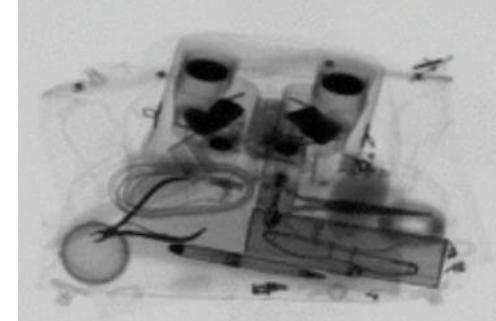
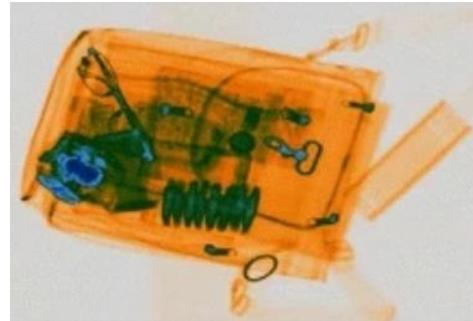
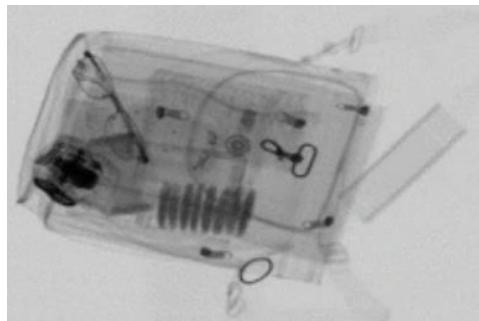


Credit: K. Dmitruk et al.

# Pseudocolor image processing

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- Transformation functions
  - with different transformation functions

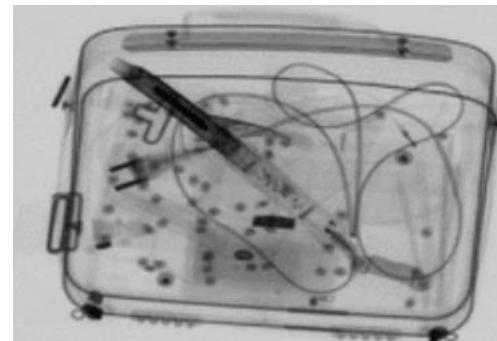
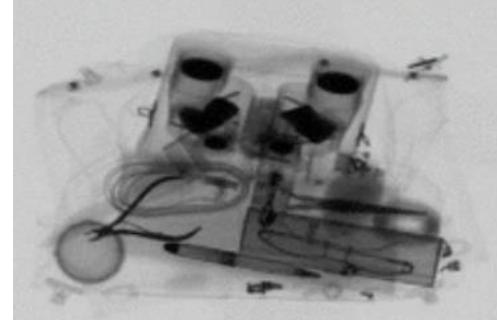
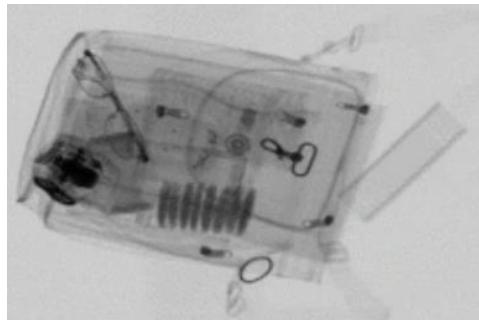


Credit: K. Dmitruk et al.

# Pseudocolor image processing

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- Transformation functions
  - with different transformation functions



Credit: K. Dmitruk et al.

# Conclusion

- Color fundamentals
- Color spaces

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- Color spaces

## ❑ Light sources

- Spectra to retina sensing

## ❑ Color

- Cones
- Color spaces
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# Conclusion

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“Blurring the pseudocolors in  
friendships, reduces the  
relational spaces & life becomes  
Colorful.”

-TS

